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# The West Lake Landfill: A Radioactive Legacy of the Nuclear Arms Race

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West Lake Landfill image courtesy of stltoday.com

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## Summary

The West Lake municipal landfill in Bridgeton, Missouri is not your ordinary landfill (see Figures 1 and 2). By virtue of the highly radiotoxic wastes dumped there, it is a *de facto* nuclear weapons legacy disposal site. Created by illegal dumping in 1973, the waste residues originated from the Mallinckrodt uranium processing plant in St. Louis which was involved in U.S. nuclear weapons program from the 1942 to the 1958.[1] The landfill:

- contains a significant amount of radiotoxic wastes that are not adequately characterized, including the potential for mobility of these wastes due to groundwater fluctuation and comingled solvents; [2]
- is in a densely populated area and has no engineered barriers,
- is experiencing the latest of at least two subsurface fires over the past 21 years;[3] [4]and
- is on the alluvial floodplain approximately 1.2 miles from the Missouri River in which the water table recurringly rises and falls by several feet, often within a few feet of the surface.

Even though these concerns were repeatedly raised with the U.S. Environmental Protection Agency (EPA) by experts[5] and nearby community members; and despite the extraordinary risks created by subsurface fires, the agency remains in support of its Record of Decision in 2008 which allows for "in place disposal" of these wastes subject to institutional controls with a cap over radiologically contaminated areas. It appears that EPA was inclined toward this decision at least eight years before it was formalized.[6]

Underscoring this situation is the presence of the largest amount of thorum-230, a long-lived, highly radiotoxic element – more than any U.S. nuclear weapons storage or disposal site (See Figure 3). The waste residues, some which were disposed in the West Lake Landfill, were found to contain the largest human-made concentration of thorium-230 (250 kg) from any single source in the United States and possibly the world. [7] Thorium-230 concentrations were found to be some 25,000 times greater than its natural isotopic abundance.[8]

With a half-life of 77, 500 years, thorium-230 makes up more than 80% of the measured radioactivity in soil at West Lake above cleanup limits set by the Department of Energy (DOE) (see Figure 4). Thorium-230 and radium-226 concentrations in the landfill are substantially greater than found at U.S. uranium mill tailings (See Figure 5). Moreover, as the thorium-230 decays to radium-226 it could increase the radioactivity and radon gas emissions in the landfill by 10 to 100 times over a 9,100 year period.[9] Given these circumstances, the West Lake landfill would violate all federal legal requirements, established over 30 years ago, for licensing of a radioactive waste disposal site.

Like other U.S. nuclear weapons legacy sites in the St. Louis, Missouri area, the U.S. Congress should seek to remove these radioactive materials and assure long-term stewardship responsibilities under the Formerly Utilized Sites Remedial Action Program (FUSRAP) managed by the U.S. Corps of Engineers and the Department of Energy.

## Figure 1 the West Lake Landfill

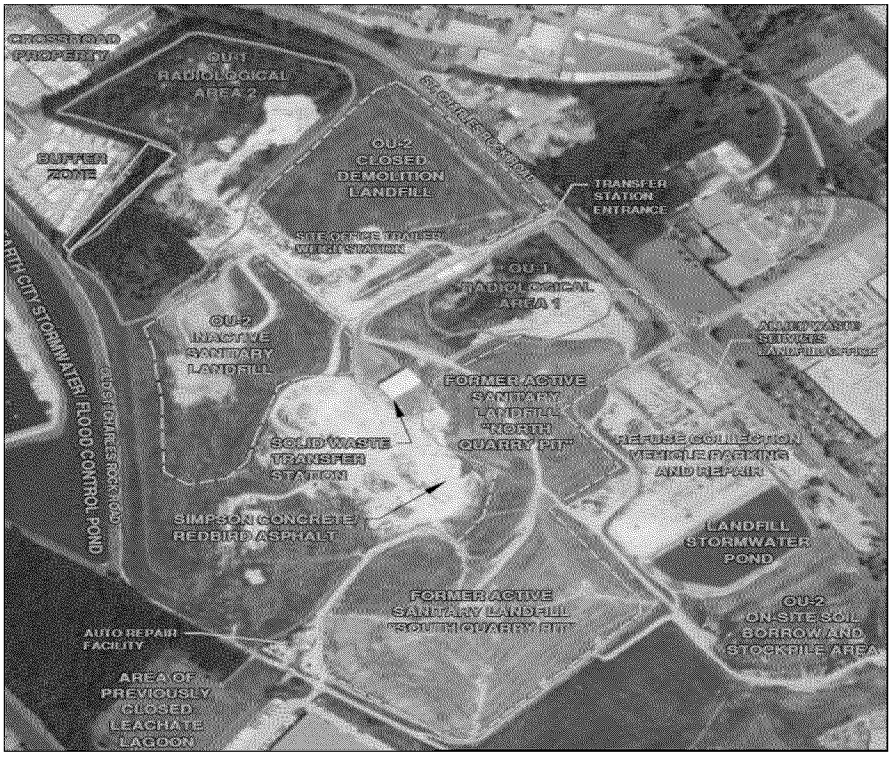



**Figure 2 Location of the West Lake Landfill**

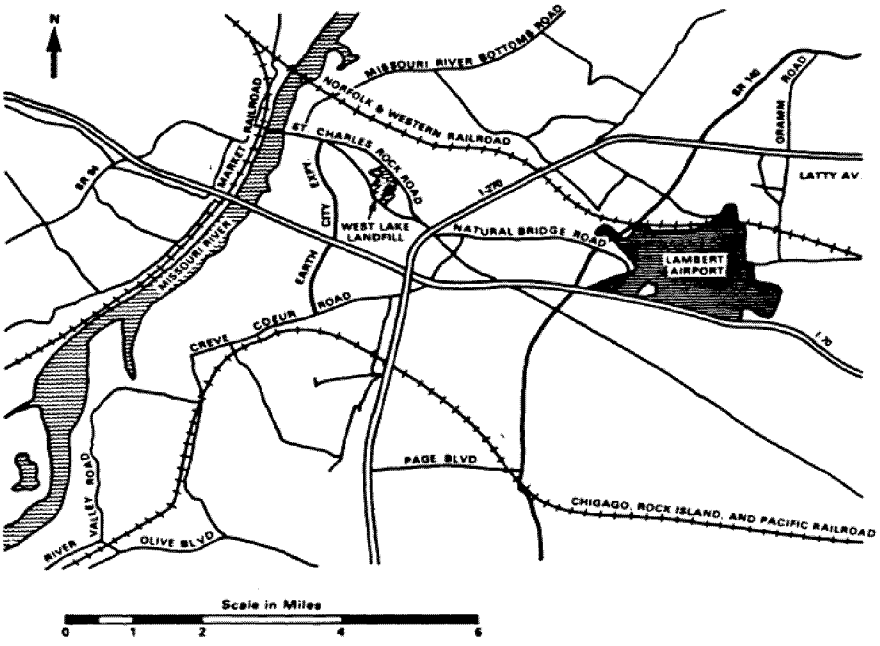
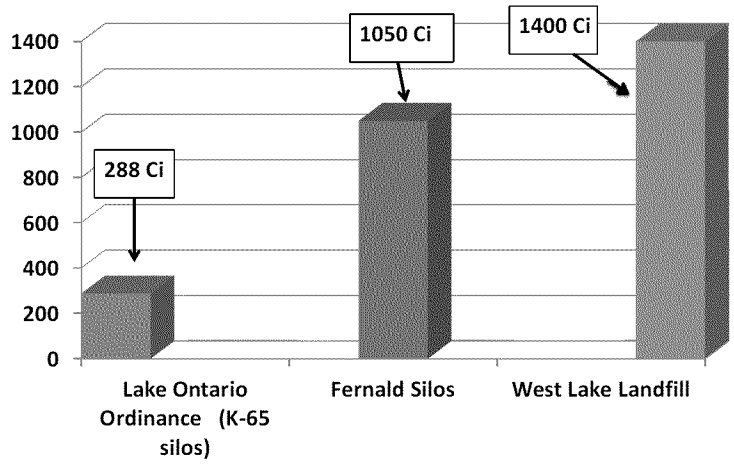
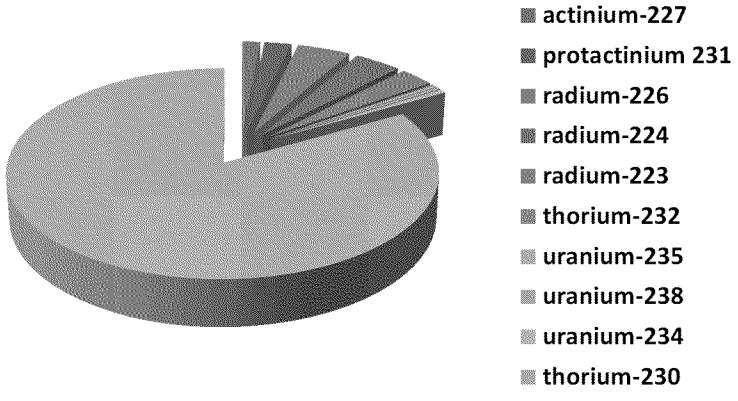


**Figure 3 Concentration of thorium-230 handled at U.S nuclear weapons sites.**



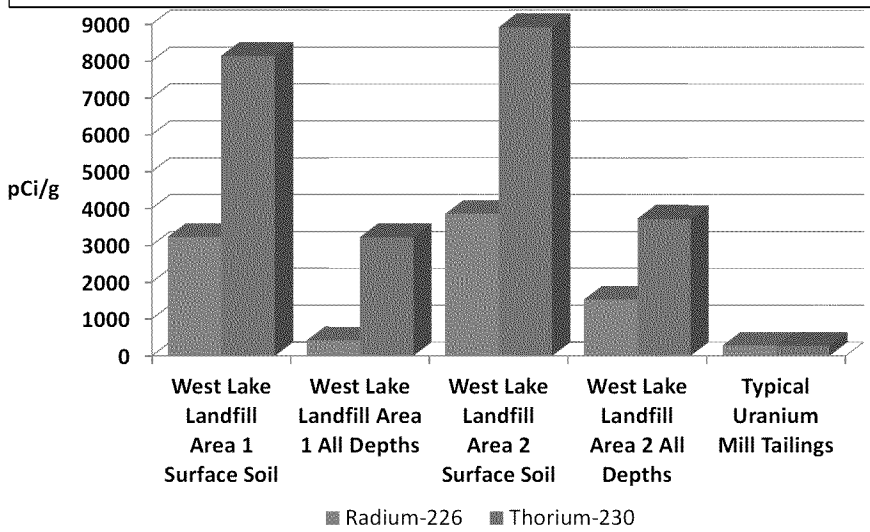

Sources: NAS (1995), (IEER 2006), NRC (1988)

**Figure 4 Radioactivity in Soil Samples in the West Lake Landfill***




*Concentrations above 5 pCi/g

**Figure 5 Comparison of the concentrations of Ra-226 and Th-230 at the West Lake Landfill with a typical uranium mill tailing pile.**




Sources: EPA West Lake ROD (2008), EPA 520/1-83-008-1 (1983)

## Thorium-230

With a half-life of 77,500 years, thorium-230 is about 60,000 times more radioactive than uranium. [10] It is categorized by the International Atomic Energy Agency (IAEA) as one of 30 radioisotopes as having "very high radiotoxicity."[11] The International Commission on Radiation Protection has recommended internal exposure limits for thorium-230 that are comparable to plutonium-239 (see Figure 6).[12] Thorium-230 emits highly energetic alpha particles, which are considered by the U.S. National Academy of Sciences to be 20 times more carcinogenic than x-rays. [13] As they lodge in the body alpha particles from thorium-230 emit energetic ionizing radiation that can damage cells of sensitive internal tissues.

According to the National Library of Medicine of the National Institutes of Health, "the most likely pathway by which the general public is exposed to thorium is by ingestion of food items. Data also indicates that the general population may be exposed to thorium compounds via ingestion of drinking water and inhalation of ambient air."[14] This is of concern if thorium-230 in the landfill comes in contact with a fire and releases breathable particles into the air. Once it is absorbed in the body, thorium has a biological half-life of 700 days. Most of the thorium (70%) has been found to lodge on the bone surface (4% to the liver and 16% to other organs) where it effectively remains throughout a person's life. An assessment of the soils at the St. Louis airport site found that most respirable soil particles contained the highest levels of thorium-230. [15]

The mobility of thorium in soil is low. However, its mobility in the environment is enhanced when mixed with reagents and solvents. [16] There are 19 organic solvents identified by a 2000 risk assessment of the West Lake Landfill that are comingled with the disposed radionuclides.[17]

Thorium-230 is also considered to have a relatively high bioaccumulation in aquatic organisms. [18]In 1993 it was reported that, " a case study of 112 New Jersey households in the vicinity of a thorium waste disposal site found a higher prevalence of birth defects (relative risk 2.1) and liver

disease (relative risk 2.3) among the exposed population than the unexposed group."[19]

The potential hazards to human health from internal exposure to thorium-230 have been a long-recognized concern by health and safety experts in the U.S. nuclear weapons program. During the 1950's, Mallinckrodt separated small quantities of thorium-230 on a laboratory scale. However, according to the National Institutes for Occupational Safety and Health (NIOSH) when asked by the U.S. Atomic Energy Commission to establish a thorium-230 pilot plant, "Mallinckrodt refused, on the basis that the health hazards of thorium were not well understood." [20] Finally the "AEC agreed that the pilot plant would be built and operated as if it were to process plutonium and the pilot plant began operation at [Mallinckrodt] on 25 February 1956." By 1957, the Health Department at the plant "recommended that they do no further processing [of Th-230] under their existing conditions."[21] In 1959, experts at the Energy Department's Hanford site noted that thorium-230 is "in a class as hazardous as plutonium."[22]

Because of the removal of uranium from the wastes disposed at the West Lake site, radioactive decay products of uranium were highly concentrated. In particular, the high ratio of Thorium-230 to Radium-226 indicates that as thorium-230 decays to radium 226, there will be a substantial "in-growth" of alpha radioactivity –meaning that the radioactivity in the West Lake landfill will increase by 10 to 100 times over a 9,100 period. [23]EPA has selected a 1,000 year time period to bound the risks associated with radium-in-growth from thorium-230 decay, when the maximum radium ingrowth occurs nearly 9,000 years later (See figure 7.)

**Figure 6**

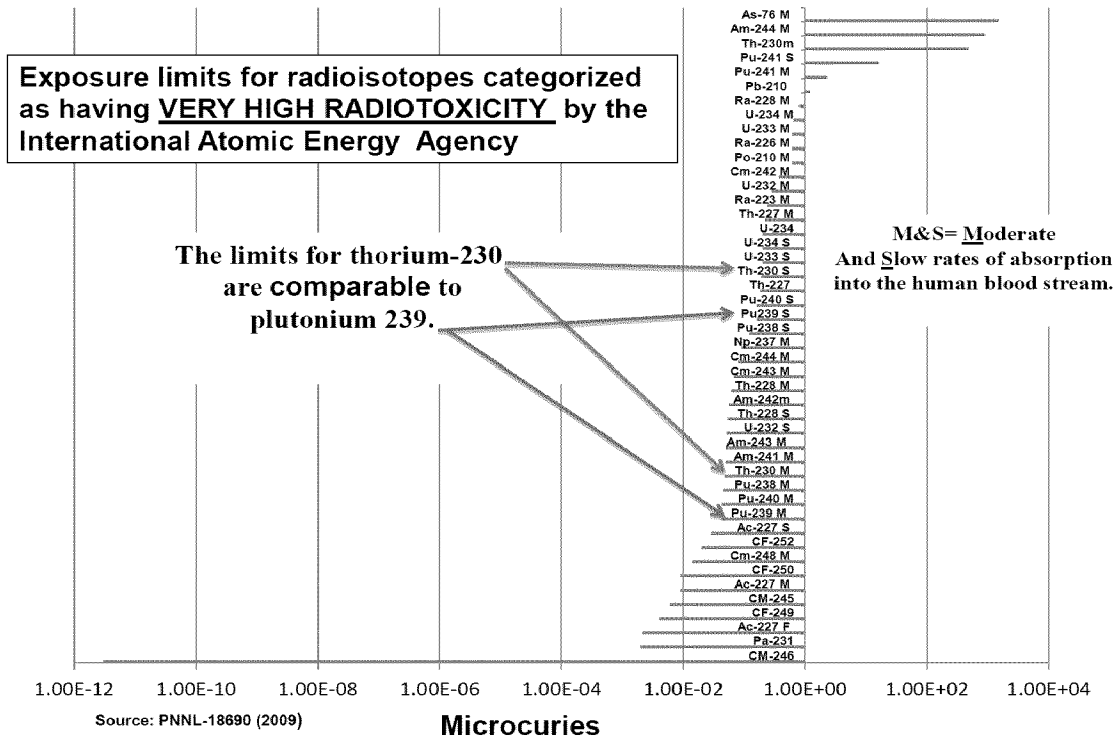
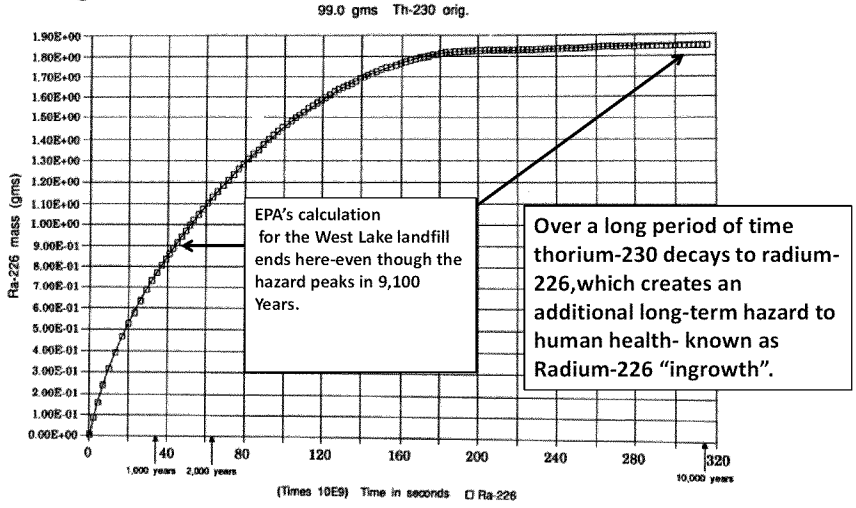


**Figure 7 RA-226 INGROWTH (GMS)**




Source:DOE/NV/10630-58 Ingrowth of Ra-226 from 99 grams of Th-230 at time t=0 years.

## Federal Requirements for a Licensed Radioactive Waste Landfill

Under current federal requirements for landfill disposal of radioactive wastes, which were adopted after the dumping occurred in the West Lake landfill, EPA's ROD would significantly violate several requirements for the selection of radioactive disposal sites (10 CFR Part 61). They include:

- The disposal site shall be capable of being characterized, modeled, analyzed, and monitored.
- The disposal site shall not be in the 100-year floodplain.
- The disposal site should provide a stable foundation for engineered containment structures.
- The disposal site should be selected so that projected population growth will not affect the disposal facility's ability to meet the performance objectives.
- Areas having known natural resources should be avoided.
- The disposal site must be well drained.
- The disposal site must provide sufficient depth to the water table.
- The disposal site must not be located where nearby facilities or activities could adversely impact the site's ability to meet the performance objectives or the ability to be monitored.

Although the West Lake Landfill contains significant amounts of long-lived radiotoxic wastes as some federally licensed commercial radioactive waste landfills, it meets none of the above legal requirements for protection of the human environment.

## Origin and Fate of the Wastes

The residue wastes disposed in the West Lake landfill were mostly generated from ore of the Shinkolobwe mine in the Belgian Congo. Described as a "freak occurrence of nature" by a top official of the early U.S. nuclear weapons program, [24] the Congo mine yielded the highest

concentrations of uranium (30-70%)[25] of any mine in the world since. [26] By comparison the Congo ore contained as much as much as 7,000 times the concentration uranium than mined in the United States.

Between 1942 and 1957, the Mallinckrodt plant processed approximately 50,000 tons of uranium of which roughly 40 percent (20,000 tons) were from the Shinkolobwe mine. [27] [28] [29] After the ore was processed to remove uranium and radium, about 133,007 tons of process waste residues and scrap resulted and were stored at the St. Louis Airport. Approximately 70 percent of the wastes stored at the airport site were from the Congo ore. Included in the waste residues were 32,500 tons of raffinate resulting from the processing of ore from the Colorado Plateau (see Table 1). Of concern to human health are the radiotoxic decay products that were concentrated above their natural abundance. Among the most significant were thorium-230, radium-226, uranium-234, Actinium-227 and protactinium-231.

In addition to uranium, hundreds of grams of radium were extracted. [30] Other highly radioactive Congo uranium wastes weighing 1,757 tons containing unrecovered radium generated at the Mallinckrodt plant were sent to the Ontario Ordinance Works in Niagara NY, and the Fernald uranium foundry in Ohio, where they were neglected for decades.

In March 1962, the U.S. Atomic Energy Commission (AEC) offered up approximately 116,700 tons of waste residues stored at the St. Louis Airport for sale. They were purchased by the Continental mining and Milling Company of Chicago, IL in April of that year for a price of $126,500.[31]

The wastes were subsequently moved to the Latty Avenue property in Hazelwood, MO. All of the wastes were deposited directly on the ground in 1966 and 1967. [32] After a turn-over in ownership, some of the residues were dried and shipped to Canon City, Colorado, by the Commercial Discount Corporation and Cotter Corporation. In 1973, the remaining residues were removed, and 30 to 40 cm (12 to 18 in.) of topsoil was transported to the West Lake Landfill in Bridgeton, Missouri.

The records documenting the disposition of the wastes sitting at the Latty Avenue site are fragmentary and incomplete. The waste piles were poorly characterized and their uranium decay product concentrations are mostly based on limited samples taken at the Mallinckrodt plant, in the 1940's and early 1950s. [33]

## Radioactive Top Soil Sent to the West Lake Landfill

According to the Nuclear Regulatory Commission, in July and August 1973, the B & K Company, under contract to Cotter Corporation illegally dumped 8,700 tons of leached barium sulfate mixed with 39,000 tons (the top 12-18 inches) of top soil from the Latty Avenue site at the West Lake Landfill. [34] The National Institute for Occupational Safety and Health described the wastes dumped in the West Lake Landfill as "the worst source" among the residues at the Latty Avenue site. "The gamma dose rates were highest from the 'aged' barium cake material.. Thus the assumption is made that the calculated doses can be based on barium sulfate as the maximal residue." [35]

In May 1974, AEC inspectors concluded that the disposal of the Latty Avenue wastes in the West Lake Landfill violated federal disposal standards, and noted that workers were instructed so that "the barium sulfate cake material was spread over a considerable portion of the site and then removed along with the top soil."[36]

The fill dirt was described as "clean soil" to the manager of West Lake landfill. [37] However, a considerable amount of evidence since the dumping indicates that the Latty Ave top soil disposed in the Lakewood Landfill was highly contaminated –containing a composite mix of the wastes residues stored there.

Top soil analysis taken during an Atomic Energy Commission –AEC (Now Nuclear Regulatory Commission) investigation of the Latty Avenue site in 1974 indicated the significant presence of uranium and thorium-bearing residues. Several surveys subsequently found that the wastes disposed in the West Lake Landfill were not only leached barium sulfate materials but also a composite of the other wastes present in the top soil of the Latty Avenue Site. For instance:

- In 1976, the NRC found soil radioactive soil concentrations" exceeding NRC criteria for decontamination of land areas 'prior to return to unrestricted use."[38]

- Top soil measurements taken at the Latty avenue site for the U.S. Nuclear Regulatory Commission in 1981, reported that, " thorium-230 levels in these soils were particularly high, ranging from ranging from110 pCi/g to 84,000 pCi/g for random samples. Biased samples ranged from 96,500 to180,000 pCi/g. The ratio of thorium-230 to radium-226 was as high as 290 to 1." [39]

- In 1993, the a risk assessment by the Energy Department reported a thorium-230 to radium-226 ratio in 9,713 cubic meters of top soil scraped into two piles at the Latty Avenue site of 157 to 1. The estimated dose to humans exposed at the point of concentration from Latty Avenue top soil was 28,000 millirem (nearly 5 times annual legal limit for radiation workers), with a fatal cancer risk of nearly 1 in 50 (See tables 2 and 3).[40] Thorium-230 is responsible for 64 percent of the dose.

## The Roles of U.S. Atomic Energy Commission and Nuclear Regulatory Commission

The wastes dumped into the West Lake Land fill were subject to direct control and nuclear regulation by the U.S. government under the Atomic Energy Act for 53 years. Generated and owned by the U.S. nuclear weapons program beginning in 1942, the wastes were sold for commercial use in 1962. After that they were subject to federal licensing and nuclear safety regulation as "source materials" under the Atomic Energy Act.

Ownership of the wastes changed hands three times requiring three separate licenses to be issued by the Nuclear Regulatory Commission (NRC) and its predecessor, the U.S. Atomic Energy Commission (AEC). When the license was relinquished in 1974, the NRC assumed responsibility for decommissioning of the West Lake Landfill and considered it to be among its top ten sites requiring a higher-level of attention and resources than several other defunct sites. In 1995, the NRC ended its control over the wastes in the West Lake Landfill by transferring responsibility for their disposition to the U.S. Environmental Protection Agency's Superfund Program.

During this period, the AEC and NRC conducted four publically available inspections and investigations, several radiological surveys, and developed plans for remediation.

- The first in 1970 found that exposure monitoring samples to protect workers "were totally inadequate to detect concentrations of radioactive materials to which persons are exposed."[41]

- In November 1974, an AEC inspection reported that 8,700 tons of barium sulfate wastes containing 7 tons of uranium and unmeasured quantities of uranium decay products, were mixed with 38,000 to 39,000 tons of top soil from the Latty Avenue site and disposed by trucks in the "St. Louis Sanitary Landfill Area No. 1on Old Bridge Road over the period July 31 through October 1973." The inspection found that disposal of these materials was in violation of federal standards in a "manner not authorized" by the AEC. [42]

- In July and August 1976, the NRC conducted a follow-up investigation after the St. Louis Post Dispatch reported that, "a St. Louis-area construction firm has dumped several thousand tons of low-level radioactive waste in a St. Louis County Landfill under circumstances that confused federal authorities about the strength and location of the waste..."[43] The article also noted that no one in a position of authority "actually saw or tested the material B&K moved to the landfill." The NRC investigation found that the location of the location and depth of the disposal was in error. The West Lake Landfill was the actual disposal site and that the radioactive residues were not covered by 100 feet of refuse. The report concluded that 8,700 tons of barium sulfate residues and 39,000 tons of top soil scraped at the Latty Avenue Site were mixed in. "The Latty Avenue surveys showed radiation levels exceeding NRC criteria for decontamination of land areas 'prior to return to unrestricted use."[44]

- From 1979 to 1993, the NRC conducted and prompted several radiological surveys, which indicated that: (a) two areas in the landfill contained high-levels of uranium decay products – with particular concerns over the long-term hazards associated with thorium-230 and radium-226; and (b) [45]as discussed previously, top soil transported to the West Lake Landfill contained high concentrations of radiotoxic uranium decay products, principally thorium-230.

- In 1988, the NRC staff issued a report which, among other things, concluded:

  "(1) There is a large quantity (on the order of 150,000 tons) of soil contaminated with long-lived radioactive material in the West Lake Landfill. Almost all the radioactivity consists of natural uranium and its radioactive decay products.

  (2) Based on the radiological surveys, the radioactive wastes as presently stored at the West Lake Landfill do not satisfy the conditions for Options 1-4 of the NRC's Branch Technical Position (BTP) regarding the disposal of radioactive wastes containing uranium or thorium residues.

  (3) A dominant factor for the future is that the average activity concentration of Th-230 is much larger than that of its decay product Ra-226, indicating a significant increase in the radiological hazards in the years and centuries to come.

  (4) Some of the radioactive material on the northwestern face of the berm has no protective cover of soil to prevent the spread of contamination and attenuate radiation.

(5) Slightly more than 8 acres of the site exceed 20 urn per hour; the highest reading of 1600 uR per hour occurs near the Butler-type building.

(6) Radon and daughters were measured at 0.031 WL in and around the Butler-type building. This exceeds the BTP [NRC's public exposure limit]…"

(7) Based on monitoring-well sample analyses, some low-level contamination of the groundwater is occurring, indicating that the groundwater in the vicinity is not adequately protected by the present disposition of the wastes.

(8) Although these radiological conditions indicate that remedial action is needed, it is unlikely that anyone has received significant radiation exposures from the existing situation.

(9) Sampling results show that chemically hazardous materials have been disposed of adjacent to or possibly mixed with the radioactive material. It is possible that part of the radioactive material has become "mixed" [both radioactively and chemically hazardous] waste."[46]

In terms of remediation of the landfill, the NRC concluded:

"(1) measures must be taken to establish adequate permanent control of the radioactive waste and to mitigate the potential long-term adverse impacts from its existing temporary storage conditions and (2) the information developed to date is inadequate for a technological determination of several important issues, i.e., whether mixed wastes are involved, and whether onsite disposal is practical technologically, and, if so, under what alternative methods. As indicated by the estimates developed by UMC [University of Missouri] remedial action will be costly."

- By 1990, after a Congressional investigation, the NRC listed the West Lake Landfill as one of 7 out of 30 sites as "Level A" requiring "priority attention in use of NRC resources for completion of decommissioning."[47]

- In 1994 an inspection report by the Nuclear Regulatory Commission concluded that the West Lake landfill "contains significant quantities of residual contamination which was the result of disposal of licensed material."[48]

- By 1995, the NRC transferred responsibility for the disposition of the illegally disposed radioactive wastes to the U.S. EPA stating, "the program being administered by EPA is adequate to protect the public and the environment from the risks associated with radioactive contamination. NRC therefore believes that its oversight of remediation at the site, in addition to that of EPA, would be burdensome and duplicative."[49]

Meanwhile after Congressional action the Army Corps of Engineers took over responsibility for the cleanup of designated sites contaminated by uranium residues from the Mallinckrodt plant in St. Louis in 1997, except for the West Lake Landfill.

## EPAs Record of Decision

The United States Environmental Protection Agency (EPA) issued a Record of Decision (ROD) in 2008 under its Superfund authority to allow for "in-place" disposal, augmented by institutional controls and the placement of a cap over the radiation contaminated areas.

The EPA notified the Nuclear Regulatory Commission that the West Lake site "will utilize cap or cover rather than soil cleanup criteria." at least eight years before its ROD was made public. If remediation were required, the EPA would rely on standards set for cleanup of uranium mill tailings (40 CFR192).[50]

Based on a 2000 Risk assessment [51] EPA's ROD assumes that the primary risks over a 1,000 year period will be to landfill groundskeepers, adjacent building occupants, and storage yard workers over the age of 19 years. By contrast, the Energy Department requires waste performance assessments involving substances such as Th-230 that include scenarios involving intruders.[52] A much smaller inventory of thorium-230 (2 Ci) was sent to the DOE's Nevada National Nuclear Security Site in Nevada which required an analysis extending out 10,000 years. [53]

In response to concerns raised about the long-term stewardship challenges associated with the radioactive wastes at the West Lake site, EPA states it "has had success locating land records in Missouri dating back to the early 1800s. Modern record keeping has greatly improved, and electronic record keeping has revolutionized the availability of data once difficult to locate and read. Many historic records have been transferred to electronic media." [54]

With respect to the EPA's decision to require a cap over the radiologically contaminated areas, EPA states: "The challenge is no greater at the Site than it is at various Superfund sites or other waste sites where long-lived radionuclides, heavy metals, or other nondegradable waste materials will be permanently disposed or managed in place.... Most of the engineering measures used at the Site will continue to be effective even in the event that institutional control becomes ineffective. The conceptual design of the landfill cover identified in the Selected Remedy relies on natural materials rather than synthetics."[55]

By contrast, the National Academy of Sciences (NAS), which was tasked to assess long-term stewardship at nuclear weapons sites, informed the Energy Department in 2000 that,"... the likelihood that institutional management measures will fail at some point is relatively high.... reliance on engineered barriers and institutional controls—are inherently failure prone...Other things being equal, contaminant reduction is preferred to contaminant isolation and the imposition of stewardship measures whose risk of failure is high...much of our current knowledge of the long-term behavior of wastes in environmental media may eventually be proven wrong." [56]

In 1986 the NAS also reported that:" the 80,000-year half-life of 230Th, the principal long-term precursor of radon in the uranium mill tailings, is very long, not only in comparison with recorded human history but also in comparison with the times in which substantial changes in the landscape occur owing to natural processes of erosion. " [57]

The radioactive wastes are considered by the NRC and EPA to be "technologically enhanced naturally occurring radioactive materials" (TENORM), which are not subject to formal federal regulations issued by the EPA or NRC. Instead EPA is "developing and providing education and guidance for safely and economically controlling exposures to TENORM wastes."[58] Because of their unique origin and hazardous properties, the Department of Energy and the Corps of Engineers do have specific regulatory requirements governing the wastes dumped in the West Lake Landfill,[59] which the EPA has chosen to not apply.

**Table 1 Summary of Residues Stored at the St. Louis Airport Site**

| Material Name | Code | Max. Inventory (tons) | Uranium Inventory (tons) | Materials Received (years) | Materials Removed (years) |
|---|---|---|---|---|---|
| **Pitchblende Raffinate** | AM-7 | 74,000 | 113.2 | 1946-1955 | 1966-67 (a) |
| **Colorado Raffinate** | AM-10 | 32,000 | 47.6 | 1946-1955 | 1966-1967 (a) |
| **Barium Sulfate Cake** | AJ-4 | 1500 | 20 | 1946-1955 | 1966-67(a) |
| **Barium Sulfate Cake (leached of radium)** | AJ-4 | 8,700 | 7 | 1946-1955 | 1966-67(a) |
| **Radium Bearing Residues** | K-65 | 1,157 | 4.6 | 1946-1948 | 1948-1949 (b) |
| **Vitro Residues** | C-6 | 290 | 1.9 | 1954 | 1966-1967 (a) |
| **Interim Residue Plant Tailings** | C-701 | 4,000 | 239 | Late 1950s | 1959 (c ) |
| **Captured Japanese Uranium-**containing sand | V-10 | 60 | 0.2 | 1954 | 1966-67 (a) |
| **C-Liner Slag** | None | 7,800 | 122.3 | 1946-1953 | 1956 (d),1966-1967 (a) |
| **Scrap Metal** | None | 3,500 | Unknown | 1946-1959 | 1962 (e) |

Source: NIOSH (2009)

(a) Sent to Latty Avenue site in Hazelwood, MO.
(b) Sent to Fernald, OH uranium plant and Ontario Ordinance Plant in NY.
(c) Sent to the Fernald, OH plant for processing.
(d) Sent to Fernald, OH uranium plant for processing.
(e) Sold and removed from the site.

**Table 2. Radionuclide Concentrations in the Composite Samples from the Hazelwood Storage Piles (pCi/g)**

| Radionuclide | Composite 1 | Composite 2 | Composite Average |
|---|---|---|---|
| **Actinium-227** | 205 | Not analyzed | 205 |
| **Protactinium-231** | 114 | 117 | 116 |
| **Radium-226** | 64 | 117 | 116 |
| **Radium-228** | 2.3 | 1.5 | 1.9 |
| **Thorium-228** | 2.1 | 117 | 2.1 |
| **Thorium-230** | 8770 | 8950 | 8860 |
| **Thorium-232** | 2.3 | 1.5 | 2.1 |
| **Uranium-235** | 3.6 | 4.4 | 4.0 |
| **Uranium-238** | 82 | 62 | 72 |

Source: DOE/OR-23701-41.1 (1993)

**Table 3. Estimated Dose and Fatal Cancer Risk from the Contaminated Hazelwood Soil Piles**

| Radionuclide | Exposure Point of Concentration (pCi/g) | Dose (mrem) | Fatal Cancer Risk |
|---|---|---|---|
| **Actinium-227** | 200 | 6,800 | 4.1E-03 |
| **Protactinium-231** | 120 | 3,000 | 1.7E-03 |
| **Radium-226** | 57 | 79 | 4.7E-05 |
| **Radium-228** | 1.9 | 2.9 | 1.7E-06 |
| **Thorium-228** | 2.1 | 6 | 3.6E-06 |
| **Thorium-230** | 8,900 | 18,000 | 1.1E-02 |
| **Thorium-232** | 1.9 | 20 | 1.2E-05 |
| **Uranium-235** | 4 | 2.3 | 1.4E-06 |
| **Uranium-238** | 72 | 41 | 2.5E-02 |
| **Total** | | 28,000 | 1.7E-02 (~1 in 50) |

Source: DOE/OR-23701-41.1 (1993)

## Endnotes

[1] Legacy of the bomb: St. Louis Nuclear Waste. St. Louis Post Dispatch, Feb, 12 -19, 1989.
[2] R.E. Criss, *Risk and Character of Radioactive Waste at the West Lake Landfill, Bridgeton, Missouri* , March 2013, http://www.moenviron.org/images/West_Lake_Photos_/West%20Lake%20Rept03142013.pdf

[3] Bridjes O'Neil, *Documents sought on radioactive landfill fire,* St. Louis American, October 23, 2013. http://www.stlamerican.com/news/local_news/article_8b8dbf58-3c49-11e3-bd9b-001a4bcf887a.html
[4] U.S. Environmental Protection Agency, Region VII, Operable Unit 2 RI/FS Work Plan, West Lake Landfill, Bridgeton, MO, prepared for Laidlaw Waste Systems (Bridgeton) Inc., by Golder Associates, Rev. 0 April 1995, p.2-39.
[5] Op Cit Ref. 2.
[6] U.S. Nuclear regulatory Commission, Memorandum for the Commissions, SECY 00-00094, Status of Decommissioning Program, Attachment 5.,April 25, 2000. http://www.nrc.gov/reading-rm/doc-collections/commission/secys/2000/secy2000-0094/2000-0094scy.pdf
[7] Ibid.
[8] U.S. Atomic Energy Commission, Mound Laboratory, *Survey of Sources of Ionium*, . October 21, 1966.
[9] Op Cit. Ref. 3.
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